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Does the type of somatosensory information from the contralateral finger touch affect grip force control while lifting an object?

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HIGHLIGHTS

- A contralateral finger touch reduces grip force while lifting an object.
- The grip force reduction is not affected by the location of touch.
- Different neural mechanisms are employed while lifting with a finger touch.

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ABSTRACT

The magnitude of grip force used to lift and transport a hand-held object is decreased if a light finger touch from the contralateral arm is provided to the wrist of the target arm. We investigated whether the type of contralateral arm sensory input that became available with the finger touch to the target arm affects the way grip force is reduced. Nine healthy subjects performed the same task of lifting and transporting an instrumented object with no involvement of the contralateral arm and when an index finger touch of the contralateral arm was provided to the wrist, elbow, and shoulder. Touching the wrist and elbow involved movements of the contralateral arm; no movements were produced while touching the shoulder. Grip force was reduced by approximately the same amount in all conditions with the finger touch compared to the no touch condition. This suggests that information from the muscle and joint receptors of the contralateral arm is used in control of grip force when a finger touch is provided to the wrist and elbow, and cutaneous information is utilized when lifting an object while touching the shoulder. The results of the study provide additional evidence to support the use of a second arm in the performance of activities of daily living and stress the importance of future studies investigating contralateral arm sensory input in grip force control.

1. Introduction

Many daily actives involving lifting objects require producing, regulating, and maintaining grip force needed to perform the task. Successful manipulation of a hand-held object depends on the exertion of forces that are large enough to prevent the slip but not too large to prevent crushing of the object or cause fatigue. To solve a pure physical problem like this, the central nervous system (CNS) relies on visual, somatosensory or alternative information while planning the grip force output according to the properties of the object and the consequences of its manipulation [4]. In particular, the rate of grip force development in healthy individuals is programmed taking into consideration the physical properties of the object, such as weight and surface friction, resulting in a smooth and well-coordinated force output at the grasping fingers [5].

It is reported in the literature that individuals with stroke, cerebellar disorders, multiple sclerosis and the elderly commonly produce inefficiently elevated grip forces while performing simple daily tasks [1,9] and that even healthy individuals exert unnecessarily large forces which are in this sense uneconomical [3].

It was shown that grip force applied to the hand-held object during its lifting and transporting could be significantly reduced when a light finger touch from the contralateral arm is provided to the target arm [1]. It was suggested that sensory cues delivered via a finger touch are the reason for the decrease of grip force. Moreover prior studies involving healthy individuals demonstrated that the finger touch-related decrease in the grip force was maintained when the velocity of lifting was varied [7], and when the finger touch was applied to different points on the forearm [6]. Particularly, it was reported that within the same arm movement velocity, the reduction in grip force with an application of the touch from the contralateral finger is not associated with touch points located on

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the forearm. The explanation to this experimental finding was that the decrease of grip force is due to the information from muscles and joint receptors of the contralateral arm, utilized together with the information from the receptors of the target arm thus allowing more efficient modulation of grip force [6]. However, since touch was provided to the forearm regions only, the somatosensory information from the contralateral arm was similar in all the experimental conditions as the range of movements in the elbow joint were relatively the same. It is also unknown whether index finger cutaneous receptors contribute to the finger-touch related minimization of grip force.

We conducted an experiment to investigate the role of different types of somatosensory information from the contralateral finger touch in reduction of grip force. The subjects applied a finger touch to the wrist, elbow, and shoulder on the target arm while lifting an object. Touching the wrist and elbow involves movements of the contralateral arm and as such, information from muscles and joint receptors of the contralateral arm could be used in control of grip force [6]. To the contrary, there are no movements of the contralateral arm while the finger touch is provided to the shoulder; as such no information from muscles and joint receptors of the contralateral arm is obtained during lifting the object with the contralateral finger touch. We hypothesized that the level of finger touch-related reduction of grip force will be affected by the availability and type of the somatosensory information from the contralateral arm.

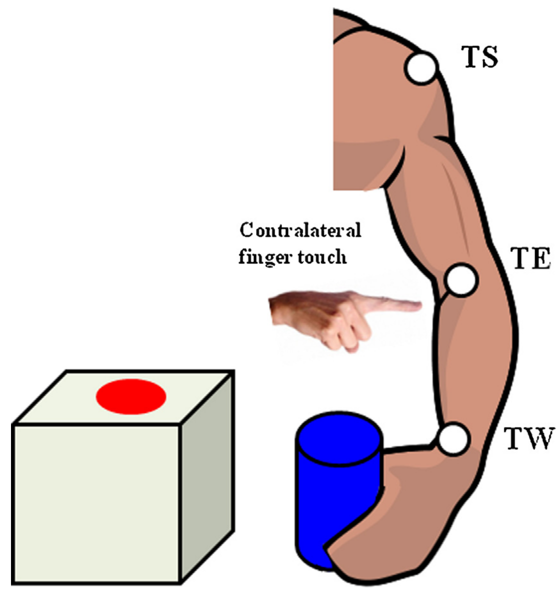

Fig. 1. Schematic representation of the experimental task.

2. Materials and methods

Nine healthy right-handed young volunteers (4 males, 5 females, mean age 28 ± 4.24) participated in the experiment. The experimental protocol was approved by the University of Illinois at Chicago Institutional Review Board and all participants provided written informed consent before taking part in the experimental procedures.

An instrumented object made as a cylindrical plastic cup (16.5 cm high, 6 cm diameter, total weight 435 g) was used to perform the task of lifting and transporting it. A strain gauge (PCB model-208c03) was located at the center of the object (10.5 cm from the bottom) and extended out from both sides of the cup by aluminum projections of 9.5 cm $\times$ 2.5 cm each. The strain gauge measured grip force applied by the thumb and four opposing fingers. A 3-dimentional accelerometer (PCB model-356a16) was attached to the instrumented object to measure the acceleration in three orthogonal directions.

First, demographic information of the subject including age, sex, height, weight and forearm length was obtained. Then the participants were asked to sit on an adjustable chair in front of an adjustable table with their trunk upright (no back support) and feet flat on the floor. Jamar dynamometer was used for measuring maximum static grip force while the subjects were in the sitting position mentioned above, keeping their arm close to the body, when elbow was flexed to 90 degrees and wrist was in mid pronation.

The experimental task involved lifting the instrumented object positioned on the top of the table and transporting it onto a shelf, by grasping the extended aluminum projections with the thumb and the four opposing fingers. The table and chair were adjusted in such a way that when a subject fully extended the arm in the anterior direction along the middle line, he/she would be able to reach the object (positioned on the surface of the table in the initial position) and put it on the shelf. The shelf, 21 cm height, was positioned 23 cm in front of the initial position of the instrumented object. The initial position and the final positions were marked with red spot stickers 7 cm in diameter. The subjects were instructed to sit on an adjustable chair in front of an adjustable table with their trunk upright, no back support, and feet flat on the floor, to grasp and transport the cup onto the shelf with the same maximal acceleration and without the elbow touching the table. This acceleration magnitude was selected based on the results of a pilot experiment and the outcome of a previous study [6]. Maximal acceleration was recorded during the task performance and the subjects were provided with verbal feedback by the experimenter after each trial; a trial was repeated if the recorded acceleration was below 4 m/s^2 or above 6 m/s^2. The experimenter provided the subjects with two instructions, first 'ready' and then 'go'. In response to the 'ready' command the subjects were required to put the fingers of the target hand around the instrumented object. However, the subjects were asked not to exert force to the aluminum projectors until he/she heard the second command 'go'. Following the 'go' signal the subjects lifted the object and put it onto the shelf. After completion of the trial, the experimenter put the instrumented cup back to the initial position for the subsequent trial. The subjects were instructed not to use the trunk movements while performing the experimental tasks. The accuracy of positioning the cup on the shelf was not taken in consideration however, if the cup was completely out of the spot, the subject was asked to repeat the trial again. Each subject was required to perform the experimental task with no involvement of the contralateral arm and with a light touch from the index finger of the contralateral arm. A light touch of the index finger was provided to the three points on the target arm: (1) ventral aspect of the wrist (TW), (2) ventral aspect of the elbow (TE), and (3) on the top of the shoulder (TS). These three points were the same for all the subjects. If the subject was touching the target arm outside of the selected three points, the trial was repeated. The light finger touch was applied immediately before the lift of the instrumented object and maintained during the whole duration of the task till the object was released (Fig. 1). The subjects were instructed to apply a finger touch without application of force to the target arm; as such, the contralateral arm-related gravitational force did not affect the generation of the grip force. All the tasks were performed with eyes open. 2–3 practice trials were provided to the subjects before collecting data, and five trials were collected in each experimental condition. The order of conditions was randomized for each participant.

The signals from the strain gauge and the accelerometer were digitized with a 16-bit resolution at 1000 Hz by means of customized LabVIEW 8.6.1 software (National Instruments, Austin TX, USA). The data were then processed and analyzed in MATLAB